Four Layer P-N-P-N Switching Devices
(Shockley Diode)
Lecture – 4

TDC PART – II

Paper - III (Group - A)

Chapter - 4

by:

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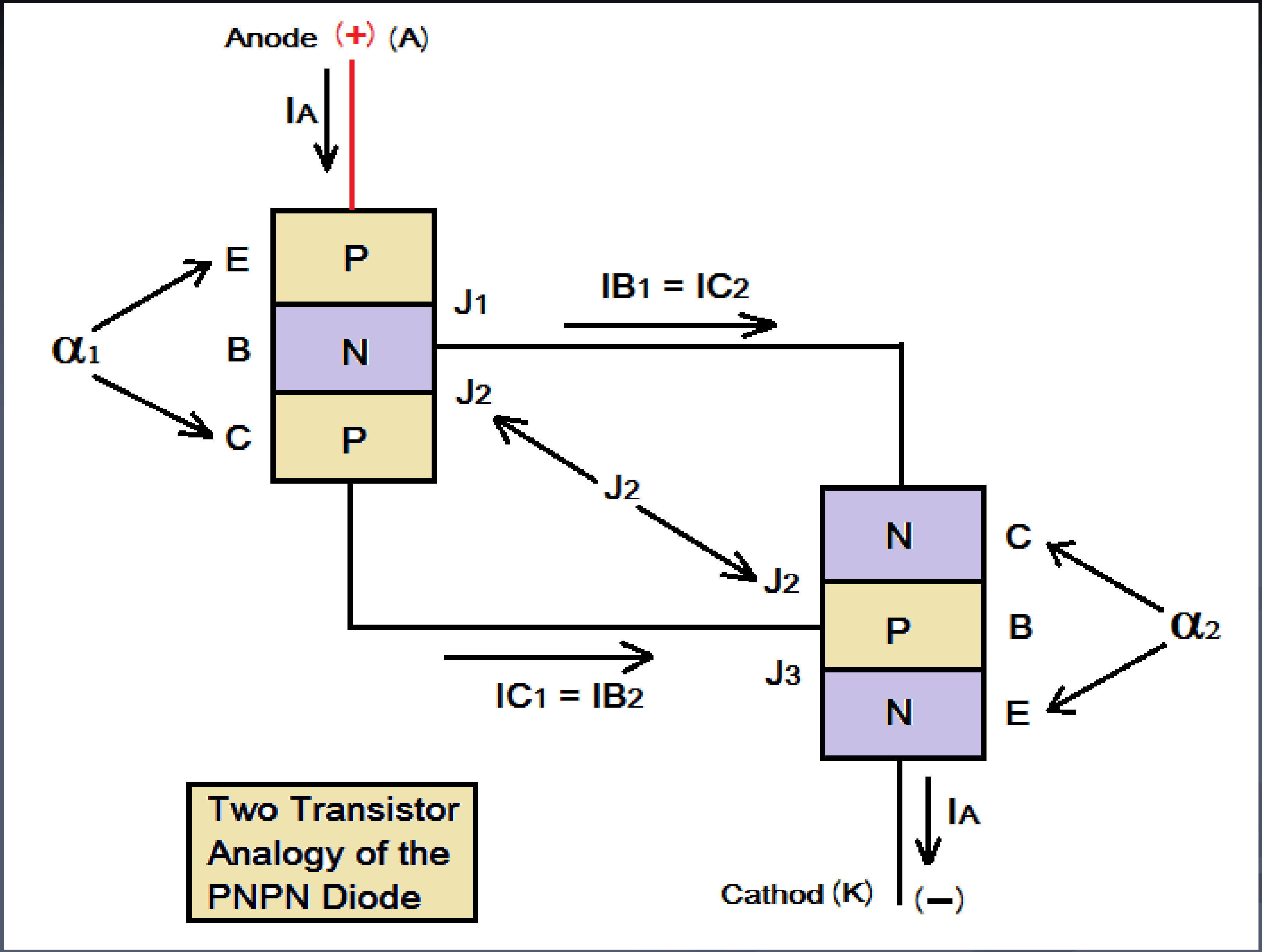
- **P-N-P-N Diode or Shockley Diode**
- **Lecture Content :-**

➢ **(4) The Two – Transistor Analogy**

P-N-P-N Diode or Shockley Diode

- **(4) The Two – Transistor Analogy**
- The **Four-layer configuration** of **Figure (3)** suggest that the **P-N-P-N Diode** can be considered as two coupled transistor **J1 and J2** form the **Emitter and Collector Junction** respectively, of a **PNP transistor;** similarly **J2 and J3** form the **Collector and Emitter Junctions** of a **NPN transistor** (Note the Emitter of the **NPN** is on the right, which is the reverse of what we usually draw).

- In this analogy the **Collector region** of the **NPN transistor** is in common with the **Base** of the **PNP transistor** and the **Base** of the NPN **transistor** serves as the **Collector** region of the **PNP transistor**. The **Centre Junction J2** serves as the **Collector Junction** for the **both transistors.** This **Two-Transistor Analogy** is illustrated in **Figure (5)** below.



- **Fig (5)** Shown Two Transistor Analogy of the P-N-P-N Diode or Shockley Diode.

- The **Collector Current I_{C1}** of the **P-N-P transistor** drives the Base of the **N-P-N transistor,** and the **Base Current I_{B1}** of the **P-N-P transistor** is dictated by the **Collector Current I_{C2}** of the **NPN transistor**. If we associate an **Emitter-to-Collector Current Transfer Ratio α** with each transistor, we can analysis to solve for the **Current Ic.** Using following equation,

- $I_C = \alpha_N I_E - I_{CO} (e^{qV_{CB} / KT} - 1)$

……………………… (1)

- **Where,**

I_C = Collector Current,

I_E = Emitter Current,

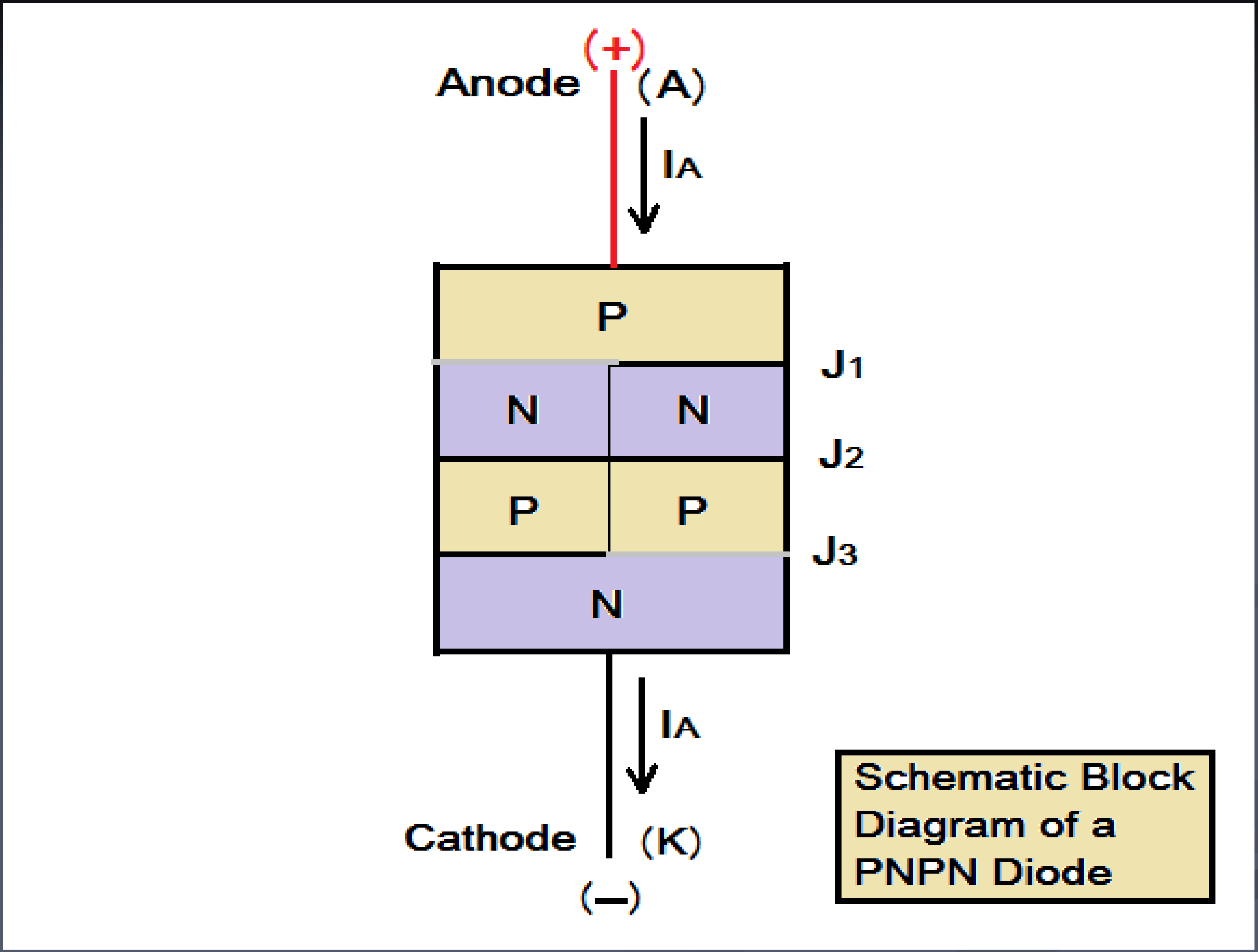
I_{CO} = Magnitude of the Collector Saturation Current,

K = Boltzman Constant,

T = Temperature,

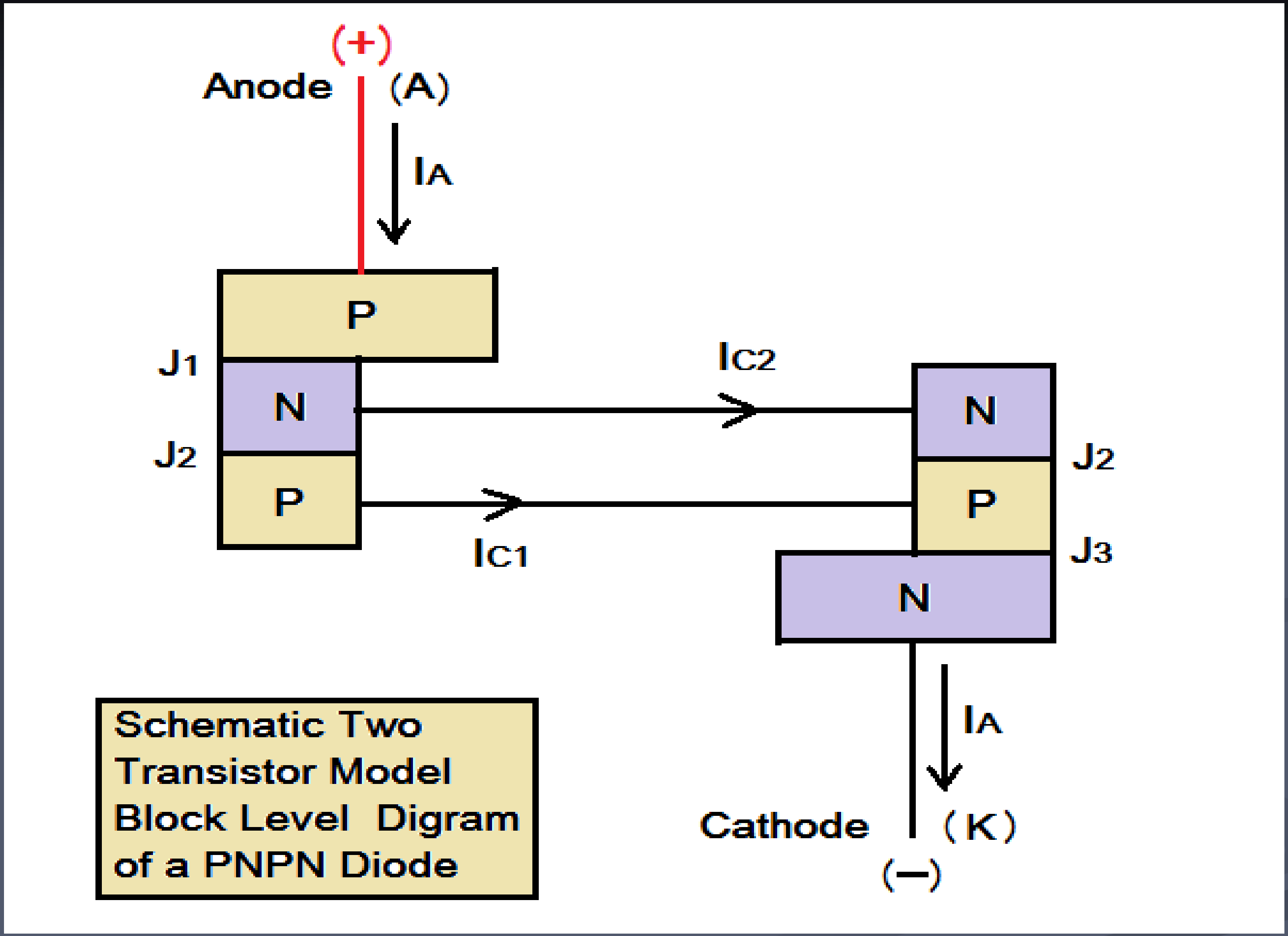
α = Emitter-to-Collector Current Transfer Ratio of a BJT Transistor.

- The principle of **P-N-P-N Diode or Shockley Diode** operation can be explained with the use of its **Two-Transistor- Model (or Two-Transistor-Analogy).** **Figure (6)** shows below schematic diagram of a **P-N-P-N Diode or Shockley Diode**.



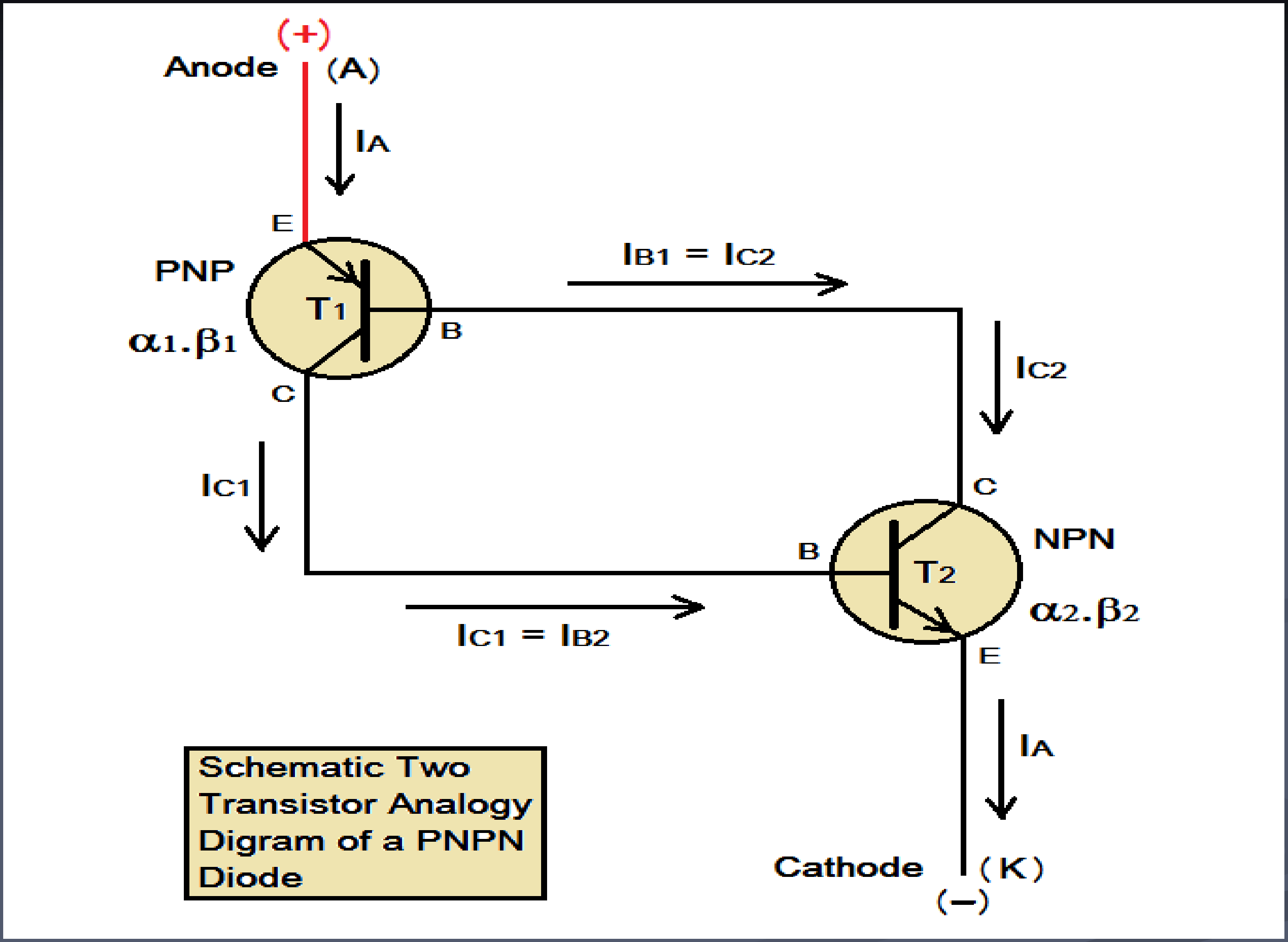
- **Fig (6)** Shown Schematic Block Diagram of a P-N-P-N Diode or Shockley Diode.

- From the above **Figure (6), Two-Transistor-Model** is obtained by **Bisecting the Two Middle Layers,** along the **Dotted Line,** in **Two Separate Halves** as shown in **Figure (7) below.**



- **Fig (7)** Shown Schematic Two Transistor Model Block Level Diagram of a P-N-P-N Diode or Shockley Diode.

- In this **Figure (7), Junction J1-J2 and J2-J3** can be considered to constitute **P-N-P and N-P-N Transistors** separately. The circuit representation of the **Two-Transistor-Model** of a **P-N-P-N Diode or Shockley Diode** is shown in **Figure (8) below.**



- **Fig (8)** Shown Schematic Two Transistor Analogy Diagram of a P-N-P-N Diode or Shockley Diode.

- In the **OFF-State** of a Transistor, **Collector Current IC** is related to **Emitter Current I_E** as,
- $I_C = \alpha I_E + I_{CBO}$

  ……………………………… **(2)**
- **Where,**

  α = is the Common Base Current Gain,

  I_{CBO} = is the Common Base Leakage Current at Collector Base junction of a transistor and

  I_E = Emitter Current of a transistor.

- For Transistor T1 from Figure (8),
- The Collector Current I_{C1} is given by,

  Emitter Current I_E = Anode Current I_a and

  Collector Current I_C = I_{C1}

- Therefore, for Transistor T1,
- $I_{C1} = \alpha 1\ I_a + I_{CBO1} = I_{B2}$

  …………………… (3)

- **Where,**

$\alpha 1$ = Common Base Current Gain of Transistor T1,

I_{CBO1} = Common Base Leakage Current of Transistor T1.

I_a = Emitter Current of Transistor T1.

- Similarly,
- For Transistor T2 from Figure (8),

The Collector Current I_{C2} is given by,

Emitter Current I_E = Cathode Current I_K

and

Collector Current I_C = I_{C2}

- Therefore for Transistor T2,
- $I_{C2} = \alpha_2 I_K + I_{CBO2} = I_{B1}$

$$\text{....................} \quad (4)$$

- **Where,**

α_2 = Common Base Current Gain of Transistor T2,

I_{CBO2} = Common Base Leakage Current of Transistor T2,

I_K = Emitter Current of Transistor T2.

- Now, the **sum of two Collector Currents** given by **Equation (3) and (4)** is equal to the **external circuit current Ia (Anode Current)** entering at **Anode (A) Terminal** of **P-N-P-N Diode.**

- **$I_a = I_{C1} + I_{C2}$**

or,

- **$I_a = \alpha_1 I_a + I_{CBO1} + \alpha_2 I_k + I_{CBO2}$ …………… (5)**

- Here we study the **Two Terminal P-N-P-N Diode.** So here **Gate Terminal** not present. Then **Gate Current Ig = 0,** then **Cathode Current IK** will be the summation of **Anode Current (Ia) and Gate Current (Ig)** i.e.,

- **Ik = Ia + Ig**

- **or, Ik = Ia + 0**

- **therefore, Ik = Ia**

- Substituting the above value of **Emitter Current I_k** in **Equation (5)** gives,

- $I_a = \alpha_1 I_a + I_{CBO1} + \alpha_2 I_a + I_{CBO2}$

- $I_a = I_a(\alpha_1 + \alpha_2) + I_{CBO1} + I_{CBO2}$

- $I_a - I_a(\alpha_1 + \alpha_2) = I_{CBO1} + I_{CBO2}$

- $I_a(1 - (\alpha_1 + \alpha_2)) = I_{CBO1} + I_{CBO2}$

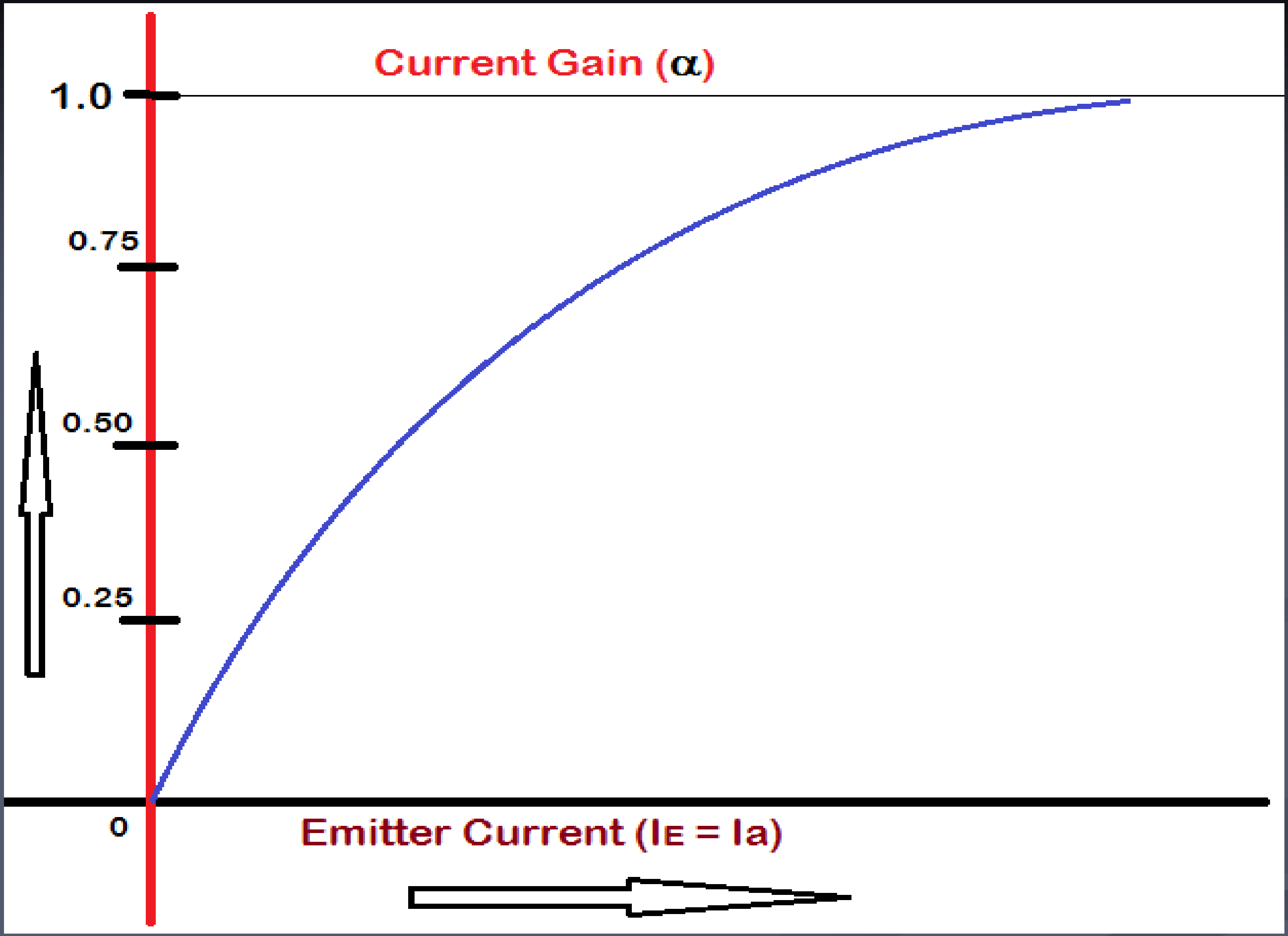
- **$I_a = I_{CBO1} + I_{CBO2} / 1 - (\alpha_1 + \alpha_2)$**

.... (6)

- For a **Silicon Transistor, Current Gain α** is **very low** at **Low Emitter Current.** With an **increase in Emitter Current, α** builds up rapidly as shown in **Figure (9)** below. With **Gate Current Ig = 0** and with **P-N-P-N Diode Forward Biased,** (**α1 + α2)** is very low as per **Equation (6)** and **Forward Leakage Current** somewhat more than **(I_{CBO1} + I_{CBO2})** flows.

- If, by some means, the **Emitter Current** of **Two Component Transistors** can be **increased** so that **$\alpha 1 + \alpha 2$** approaches **Unity,** then as per **Equation (6), Anode Current Ia** would tend to become **Infinity thereby Turning-ON** the **P-N-P-N Diode or Shockley Diode device.**

- Actually, **External Load Limits** the **Anode Current Ia** to a safe value after the **P-N-P-N Diode begins Conduction.** The methods of **Turning-ON a P-N-P-N diode or Shockley diode,** in fact are the **methods of making $\alpha 1 + \alpha 2$** to **approach Unity.**



- **Fig (9)** Shown Typical Variation of **Current Gain (α)** builds up with **Emitter Current (I_E) or Anode Current** of a Two Terminal P-N-P-N diode or Shockley diode.

- **In other word,** as **Equation (6)** indicates, the **Anode current Ia** through the **P-N-P-N Diod**e devices is **small** (approximately the combined Common-Base Leakage Current of two equivalent transistors) as long as the **Sum $\alpha 1 + \alpha 2$** is **small** compared with **Unity.** As the **Sum of the Alphas approaches Unity,** the Current **Ia = I** increases rapidly.

- The current does not increase without limit at **Equation (6)** implies, however, because the derivation is no longer valid as **α1 + α2 approaches Unity.** Since **Junction J2** becomes **Forward Biased** in the **Forward Conducting State, both Transistors Become Saturated after Switching.** The **Two Transistors remain in Saturation** while the device is in the **Forward Conducting State,** being held in **Saturation** by the **device current.**

to be continued …………..